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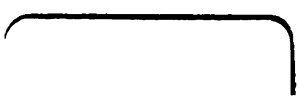

THE MONT CENIS TUNNEL.

100

THE MONT CENIS TUNNEL

ITS CONSTRUCTION

AND

PROBABLE CONSEQUENCES.

"Nil mortalibus arduum est."—HORACE.

LONDON:
CHARLES J. SKEET, 10, KING WILLIAM STREET.
CHARING CROSS.
1873.

186. f. 45.

PREFACE.

ALTHOUGH a year, or a few weeks more than a year, may have elapsed since a railway carriage first passed through the Mont Cenis Tunnel, it can scarcely be supposed that the interest regarding it has died away. It was said by a great writer, "Peace has its victories no less renowned than war," and certainly there have been few greater triumphs of science in these days than the tunnelling of the Alps. As a specimen of engineering skill, this tunnel through Mont Fréjus, which is nearly eight miles long, is almost un-

equalled. But any one wishing to form an accurate notion of the difficulties which had to be surmounted by the Italians, would probably take into account the numerous other tunnels which had to be constructed by way of approach to the great tunnel. Thus the new line of railway, or branch line to the tunnel through Mont Fréjus, passes through eleven tunnels on the Northern, and twenty-five tunnels on the Southern side, besides crossing fifteen long viaducts. The number of labourers employed near the entrances of the great tunnel seldom fell short of fifteen hundred. Moreover, the height of the superimpending mountain rendered it almost impossible to sink shafts for giving air to the workmen to breathe, and prevented the use of steam which would have been inoperative in a vacuum. A great victory, however, has been gained by science, and all the fruits

of this victory would not be lost even if the Mont Cenis Tunnel were destroyed, because the mechanical means which were invented, or discovered, for the purpose of its construction, might doubtless be successfully applied to tunnelling other parts of the Alps.

Apart from its being a work of science, the Mont Cenis Tunnel, as it is called, may also be valued for its utility. The ranges of the Alps have always been more or less a barrier to the intercourse of Italy with the Northern countries of Europe. Several centuries ago this barrier or impediment was unimportant; but as the Northern countries advanced in civilization, the effect of this mountain-barrier was to cut off Italy from participation in their growing prosperity, and to reduce it to a state of comparative isolation. It became highly desirable to supersede those steep and circuitous

mountain roads, which were often difficult and sometimes impassable, by a new mode of entering Italy from the North which might be practicable at all seasons. Therefore the Mont Cenis Tunnel must be useful to Italy but not to Italy alone. It has already become the highway from England to India, to some extent for goods, but still more for passengers, who consider the route by the Mont Cenis Tunnel and Brindisi, not only the shortest but the pleasantest way to the Presidencies of Bombay, Madras and Calcutta.

Viewed, therefore, in any light, the Mont Cenis Tunnel must be regarded as a great victory in the interests of Peace, a victory which may tend to bind nations together in friendly intercourse, a triumph of science over difficulties, and even a subjugation of the elements, inasmuch as the waters of the Alps were utilized for the purpose of compressing the air, and

the air thus compressed was made available for blasting the rock. Accordingly the author of this little work, believing that the interest excited by so novel and gigantic an undertaking as the Mont Cenis Tunnel has not yet died away, has endeavoured to trace the project of it from its dawn in the mind of an Italian peasant to its consummation. If there be truth in the lines of the poet,

> "Honour and shame from no condition rise,
> Act well your part there all the honour lies,"

it may be said that the peasant Medail who gave many an hour, both day and night, to the consideration of a plan for breaking down the barrier of the Alps by means of a tunnel, acted a noble and honourable part. His plan of tunnelling the Alps between Bardonecchia and Modane received the approval of eminent engineers, and was finally adopted. How-

ever, the embarrassment of the finances arising from the war of independence caused a delay of several years, and Medail did not live to see his hopes realized. But justice to his memory would seem to require that the name of Medail should be remembered and honoured.

Though the author of this little work has visited the Mont Cenis Tunnel, he has not limited himself to the information which he acquired in the adjoining localities. He has endeavoured to consult the best authorities on the subject, and he cannot finish this Preface without stating that he has been much indebted to a work entitled, "Guida al Traforo del Cenisio," which he would venture to commend to his readers, if they are desirous of knowledge about the grand and beautiful scenery in the neighbourhood of the Mont Cenis Tunnel.

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THE MONT CENIS TUNNEL.

CHAPTER I.

PROJECTS FOR TUNNELLING THE ALPS.

ADDISON remarks that Nature seems to have laid out Italy in a variety of States and Governments. The Alps at one end of it, and the ranges of the Apennines which pass through the body of it, branching out as they do on all sides, served as so many natural boundaries to the territories which lie among them. Thus was Italy, to borrow the words of Addison, cut into a multitude of Kingdoms and Commonwealths. At length, engineering science removed these boun-

daries or impediments of Nature and, if it did not go the length of fusing the different States of Italy into one, it rendered the intercourse between these States no longer a matter of difficulty. In removing these natural impediments there has been a vast amount of engineering skill, for many hills or mountains had to be pierced and many tunnels constructed. Thus, although the journey between Bologna and Pistoia may be performed in little more than four hours, there are as many as forty-two tunnels. However, the greatest triumph of engineering science in the way of tunnels has probably been the Mont Cenis tunnel, as it is somewhat inaccurately named, which great and successful undertaking we propose to make the subject of a few remarks.

Although united under the same sceptre for about six hundred years, Savoy and

Piedmont were physically separated from each other by the barrier of the Alps. The first idea of breaking down this barrier, or of piercing the Alps, did not originate with any Government but with a humble peasant. As far back as the year 1832, Joseph Medail, a native of Bardonecchia, presented to Charles Albert, King of Sardinia, a design for opening a railway from Piedmont into Savoy by means of a tunnel from Bardonecchia to Modane. In the year 1843 he presented to the Chamber of Agriculture and Commerce at Chambéry a plan which was similar in design and which was accompanied with many particulars. The plan of this humble peasant met with approval, but during his lifetime means were wanting for its accomplishment.

The Sardinian Government had gradually become desirous of uniting Genoa

to Turin, and Turin to Chambéry in Savoy by a line of railway. It had become fully alive to the advantages which must arise from tunnelling the Alps, one of which advantages would be that the commerce of Europe generally would flow more easily into Italy. Other advantages besides were expected to result from such a work, which are expressed in a journal published soon after Medail had conceived the idea of it in the following words: "The Piedmontese will form a whole more compact and more homogeneous by means of the fusion of Genoa and Savoy. Possessor of the key of the Alps, placed between France and Austria, its power will increase by means of the importance of these passages, of which alone it will be the master, because, for it alone, the Alps will be practicable in all times and with all rapidity.

In the year 1845 the Sardinian

Government invited Maus and Sismonda to occupy themselves with preparatory studies for making a tunnel through Mont Cenis. Sismonda was a very able geologist and mineralogist; Maus was eminent as an engineer. He had acquired his eminence among engineers by a new system of locomotion, known under the name of "inclined plane of Liege" which was applied to the railway of Ostend. He afterwards applied this system, which involved the use of cables, to part of the railway between Turin and Genoa. At the bidding of the Sardinian Government, Maus and Sismonda made investigations of all the tracts of the Alps which extend from Mont Cenis to Mont Genèvre and they came to the conclusion that the site most opportune for the excavation of a tunnel was that already pointed out by Medail between Bardonecchia and Modane.

About this time Maus caused numerous experiments to be made on the resistance of local rocks to the chisel of the miner. He thought that it would require nearly forty years to make the intended tunnel in the ordinary way. As such a plan would be tedious, expensive and even uncertain, he gave his attention to the creation of a machine for cutting the rock rapidly. In 1846 he obtained from the Sardinian Government a credit for the construction of a perforating apparatus of his own invention, destined to cut the rock by means of a great number of chisels or foils, which should be able to act by a rapid and alternative movement. This apparatus, conceived or invented by Maus, was well constructed by Thémar. Some experiments were made by it in the valley of the Oc near Turin. The mechanism was composed of parallel rows of chisels very near one another, and able

to glide horizontally in the holes of a frame. The chisels carried a firmly fixed muff, which made them turn round their axle and also recoil by the action; during which action they compressed powerful springs, which hurled them into the holes or cuts and notches. Huge blocks of stone were brought from the neighbouring Alps, against which the machine, with all its chisels advancing and recoiling, after being set in motion by the water of a mill in the valley of the Oc, was successfully exercised.

In the early part of the year 1849 Maus presented to a Commission at Turin a detailed report of his plan for making a tunnel through the Alps. He fixed the length of this tunnel at 12,290 metres with an unique declivity or slope towards Modane of $0^{m}0188$, so that the entrance near Bardonecchia, which marked the most elevated point of the line, would

have been placed at 1,364 metres above the level of the sea. On account of the greater elevation at the one end, Maus intended to establish eight inclined planes of about five kilometres each in length, and in aid of these inclined planes he proposed the invention which he had successfully introduced at Liege, but with this sole difference in the tunnel of the Alps, that the motive force would not be supplied by steam-power but by the water of the numerous torrents which would be met with along the way. He conceived in the first instance that his perforator should be moved by a fixed machine, placed at the entrance of the tunnel at either end, the torrents near the two entrances being employed as motive force for that purpose. In order to supply the air necessary to the workmen in this long subterranean place, he proposed to apply to the pivots of the

pulley-wheels, over which passes the rope for the transmission of the motive force, some fans or ventilators, which on the one side would inhale the air and on the other drive it into a tube. In order to clean the part cut, and also prevent the rapid heating of the foils of the machine, it became necessary to project water with force near the part cut away. Maus provided for this want by placing on his apparatus a powerful hydraulic pump moved by the same motive force as the perforator, and drawing up the water in a reservoir situated in the neighbourhood. This motive force was obtained by means of exterior hydraulic wheels, with small troughs, borrowing their action from the torrents of the Arc on the North side and the little river of Rochmolles with other tributaries on the South side. For the transmission of the motive force of these wheels, Maus had

adopted cables in iron wire of forty-four kilometres of diameter carried on pulleys ten metres apart. Provided this plan of Maus had been carried out, there would have been a cable in the subterranean way about 13,000 metres long, supported by 2,400 pulleys fixed on the interior soil or ground.

The swiftness of this cable was calculated at twelve metres per second, while the number of blows which the 116 foils or chisels at the end of the machine ought to give was estimated at 150 per minute. At this number, which supposed eighty-three horse-power transmitted to each perforator by the cables, the advancement was estimated to be at the rate of five metres per twenty-four hours at each end of the tunnel, or 3,650 metres per annum.

It was apprehended that there would be an accumulation of foul air in the

workings of this long tunnel. In the construction of tunnels it is no uncommon thing to sink a number both of working shafts and air shafts. The former serve to enable the workmen to proceed in a number of given places at once, by which means the execution of the work is shortened, the latter to give fresh air to the workmen. But while both were most desirable in a tunnel of such great length as that of the Mont Cenis, they were rendered impossible by the superimpending height of the mountain to be pierced or excavated. Maus hoped to be able to drive back the foul air in a tube by placing ventilators on some of the pulleys of support of the cable. In order, however, that such a system should be complete, a special pipe of strong diameter and of length equal to the tunnel would be requisite. But whatever were the defects of the pro-

ject of Maus, it was so favourably received by the minister Paleocapa, that the report of the Belgian engineer was printed in French and Italian at the expense of the Sardinian Government, and copies of it were circulated among scientific bodies. Numerous discussions ensued, chiefly among engineers, but without any important result until the year 1852.

The idea of replacing the cable of Maus by the circulation of air at a very high tension and of employing this air in different useful functions is unquestionably that which has most contributed to the success of the Alpine tunnel. After a short interruption caused by the war of independence fought with adverse lot in 1848, by the exhaustion of the finances, and by the discouragement of the people, the Italian Government renewed its efforts to make a railway through the Alps, not

only by publishing reports on the projects of a tunnel through Mont Cenis, but by doing its utmost to invite engineers of all countries to address observations to it on the subject.

Among the plans submitted to the Commission of Turin, we have referred to that of the eminent engineer Maus. In spite, however, of the successful experiments in the valley of the Oc, his project with the cable had many defects. The chief of these were the heavy cost, a bad ventilation and a considerable waste of motive power. Men of science accordingly exerted themselves to find some better project. One engineer suggested the employment of a vacuum by means of a long continued tube. But a tube of very great diameter would have been requisite, and moreover it would not have been easy to transport by this means twenty-eight horse power to the per-

forator. It may here be stated that about this time several eminent engineers regarded the idea of tunnelling the Alps as one impossible to be realized.

It was, however, known at this epoch that gases are able to circulate in tubes of great length; but it was impossible to rest on any experience for calculating their resistance under pressures of certain atmospheres, and it was quite unknown that a power so considerable as that of eighty or a hundred horse could be transmitted to the distance of six thousand metres in tubes of twenty to twenty-five centimetres of diameter.

The only engineer who from 1849 to 1852 had made experiments for the purpose of demonstrating such a possibility was the professor Daniel Colladon, of Geneva, *savant* already known by several works in mechanics and physics, formerly professor at the central school of Paris,

and who had occasionally been occupied in researches on the compression of gases and of liquids, on the heat disengaged by this compression and on the circulation of the gas of lighting in tubes. Colladon was engineer of gas manufactories and in 1849 he occupied himself with processes of his own invention for weakening the resistance of the air circulation of the gas in tubes. Even so far back as the year 1826, he had sent to Brunel a memoir in which he proposed the employment of compressed air for the construction of the tunnel under the Thames.

Colladon having read the various reports published at Turin, occupied his mind with the thoughts of discovering some more perfect means of ventilation and also of transmission of force. He endeavoured to obtain information about the possibility of transmitting considerable force by the circulation of gases. He

studied accordingly how it would be possible to reduce the resistance in tubes of cast iron, either by mechanical process or by some amelioration of their interior surfaces such as could be introduced by the heads of foundries. He did not think it important that the metal should be cast iron, but he thought that more depended on the degree of polish than on the chemical nature of the metal. It happened, however, that Colladon's studies of the subject and the numerous experiments which he made in connexion with it were interrupted in the year 1851 by an official visit to London at the time of the Exhibition.

Maus, who was director of the works from Genoa to Turin, exercised about this time much influence. Menabrea, who entertained a favourable opinion both of Maus and Colladon, introduced these two engineers to each other. Maus preferred

his plan with the cables to that of Colladon. But the Genevese engineer published in the month of December 1852, a memoir or report of his invention for piercing the Alps with tunnels by means of compressed air. He went far to demonstrate that the air experiences in the conducting-tubes a resistance much less than was supposed, and that it could thus be conducted great distances while still preserving enough of its elastic force. According to this report, the chief objects which Colladon had in view, appear to have been the transmission of the motive force, the storing of this force while the tools were at rest, the ventilation of the mine, the regulation of the temperature in the tunnel, the watering of the cavities in the piercing and their rapid drying by the power of compressed air, and also the measures necessary to be adopted before

attacking the rock or stone of the projected tunnel.

About the month of June, 1855, an English engineer, Thomas Bartlett, undertaker of the works on the line from Chambéry to Culoz (line of the Victor Emanuel railway) in which he had to make several short tunnels, demanded a patent in Piedmont for an entirely new perforating machine. This apparatus presents two little successive cylinders, laid and solidly fixed on the same frame, which can be advanced by means of a longitudinal catching of one wheel into another, and by a rochet-wheel like a frame of a saw-mill. It could also take different degrees of inclination. One of the cylinders is the moving cylinder; it is a little steam-engine at high pressure. The second cylinder is longer; this is the cylinder of the perforator or pneumatic cylinder. It is open at the extremities.

The last cylinder, the cylinder of the perforator, has two pistons, which may here be called A and B. The piston A is fixed to the stem or stock of the mover, being prolonged for this purpose, and it participates in all its movements. The piston B carries a long bar or foil of miner, which is able to turn around its axis. Between A and B there is air. If A recoils, the air will be dilated, from whence will result for B an aspiration or suction of air and a recoil. If A advances, it compresses the air in the cylinder and chases B forward. From these two contrary effects results the game of attack of the miner's foil, alternately attracted and driven back. There were cushions of air which hindered the shocks from transmitting themselves to the mover. There were also lateral valves which were so acted on by the pistons A and B as to

make the air alternately escape and enter again.

The apparatus is accompanied by a forcing pump of water, like that which belonged to the perforator, Maus, for the watering of the holes during the boring.

This ingenious machine, invented by Bartlett, was tried in 1855 near Chambéry. There it struck between 250 and 300 blows per minute, and in ten minutes made holes in the granite about thirty-three centimetres in depth. The merit of the Bartlett machine was in the rapidity of its perforating action; its defect lay in the necessity of its propulsion by the power of steam, which would be inoperative in a vacuum. The inventor of this machine had also not foreseen the obstacle to piercing the Alps existing in the want of air to be breathed by the workmen.

It may here be remarked that the two inventions which most contributed to the

success of the Alpine tunnel, were those of Colladon and Bartlett, and that the credit of modifying those two inventions, and adapting them to the piercing of the Alps, is due to the engineers, Sommeiller, Grandis and Grattoni. Two years before the experiments of Bartlett, and as early as the Autumn of 1853, these engineers, who were then pupils of the University of Turin, had made a demand for a patent for utilizing falls of water in the compression of air. They had been named engineers for part of the line between Genoa and Turin. At the mouth of the Giovi tunnel, which is nearly two miles long, there is a great declivity. Here, Sommeiller, Grandis and Grattoni intended to propel the convoys along an inclined plane, for which purpose they had constructed a machine for compressing the air, and a tube propeller about 200 metres long. This machine, or

ram as it is called, required for each effective atmosphere a vertical height of five metres, so that for seven atmospheres a vertical height of thirty-five metres would be required. Therefore, the hydraulic power of this machine, for compressing the air, which had been invented by Sommeiller, Grandis and Grattoni, would be in proportion to the fall of waters or height of the cascade. Calculating on the assistance which they would derive from the cascades amid the Alps, these three engineers, after convincing the two Statesmen, Cavour and Paleocapa, of the probable success of their enterprise, submitted to the Piedmontese Parliament the proposal of a new system of perforation. This happened at the sitting of the 17th of June, 1856, and about two days afterwards the Chamber unanimously voted that the Government should be requested to proceed without delay in such

a course of experiments as might serve to fix in a definite manner the project of perforating the Alps with a tunnel.

The experiments were made in April and May, 1857, at Coscia, near San Pietro d'Arena, with the invention of the Italian engineers, of which the following may be considered a brief description. The foil which is destined to pierce the rock is enclosed in a cylinder in which is made to arrive at will the compressed air. The piston is at once the chisel-holder and the driving-piston, and on its rod-spear head the boring tool is fastened. This rod has a surface of section different from that of the piston; in other words the two surfaces of the fluid on the piston are very unequal. The impulsion of the tool forward is more unequal than the repulsion backward. The compressed air pushes always the piston backward with the same force; the impulsion more

powerful forward, is alternated and regulated by the drawer. Thence arise the two movements of advance and recoil.

The experiments made with the machine of which a brief and imperfect sketch has just been given, were all satisfactory. It had been apprehended that in consequence of compression the air might be carried to too high a temperature; the experiments at Coscia demonstrated on the contrary, that the external temperature never exceeded thirty degrees, in consequence of the continual renewing of the column of compressing water. It had been apprehended also that within the tunnel, at a considerable distance from the works outside, there would have been a loss of pressure so great as to render impossible the work of the machine; the trials then repeated supplied sufficient evidence for the purpose of deducing, with certainty, that even at the distance of

6,500 metres, that is to say more than half of the tunnel of the Alps, the loss of pressure would be so slight that the works could not suffer any impediment.

CHAPTER II.

EXCAVATION OF A TUNNEL THROUGH MONT FRÉJUS.

So successful were the experiments at Coscia, that the Commission authorized by the Government to study the new system of perforation, of which Sommeiller, Grandis and Grattoni were authors, made a favourable report. The Parliament accordingly approved their project of the Alpine tunnel, and, moreover, the King of Sardinia, on the 31st of August, 1857, by firing the first mine inaugurated solemnly the works.

There existed, however, numerous wants, both at Bardonecchia and at Modane, and until these wants were re-

medied, scarce any progress in the works of the Alpine tunnel was possible. It was necessary to construct roads, store-houses, offices, magazines, dwelling-houses for the workmen, water channels, and many things besides. Such works as these were rendered very difficult by the Alpine and wild nature of the places. At the same time they commenced excavating the tunnel by a mining bar worked with the hand, which mode of operation was continued till the month of January, 1861.

During the work of excavation the waters of the Arc on the Northern, and those of Melezet on the Southern, side were utilized in order to raise the volume of water necessary for the play of Sommeiller's machines. These large machines supplied with valves at the top and with hydraulic regulators, were ordered in Belgium, and when set up they cost a hundred and twenty thousand francs.

They were twenty in number, ten being for use at Bardonecchia and the other ten at Modane.

At first the works were exposed to inundations. Thus when the water was troubled, the play of Sommeiller's apparatus became irregular and the pressure insufficient. The result was that the reaction of the air for a brief space of time, more powerful than twenty-six metres of water, hurled in instantaneous vertical waterspout a mass of six thousand centimetre cubits of water, which carried away the roofs and inundated the workshops, besides causing other damages. In course of time various defects were remedied and various improvements introduced. It was discovered that a much larger volume of air could be compressed by means of hydraulic pumps. This increased compression was carried to the extent of seven atmospheres with advan-

tage both to the workmen and the progress of the works.

In the months of October and November, 1857, the piercing by work of hand was commenced at the two extremities. So slow was this operation during the first three years and two months, that if the work had continued progressing only at this rate the tunnel could not have been finished in much less than forty years. However, in January, 1861, the perforating machines were introduced into the bowels of the mountain at Bardonecchia, and about two years later on the opposite or Northern side, near Modane. From that instant the gravest difficulties may be said to have been overcome, so that as far back as the year 1861 the excavation of a tunnel through Mont Fréjus might have been almost regarded as a work the execution of which depended on time. Nevertheless, through some defect of the

perforators or inexperience of the workmen, the advance the first year was even less than that of the previous work by the hand. In the following year there was a slight increase in the progress made on the South side near Bardonecchia, where the advancement by means of the perforators was rather more than a metre a day. But this daily progress on the Sonthern side was more than doubled before the completion of the tunnel. On the Northern side, where the manual labours lasted longer, the work with the perforators did not begin until January, 1863. There the rock more resisting, retarded the achievement. But the progress, though slower, was more equal. About July, 1866, they encountered great difficulty in coming upon a bank of quartz. The locality of this quartz would seem to have been announced by Sismonda. That professor had fixed the distribution of the rocks in the following order from Modane

to Bardonecchia, viz., sandy micaceous matter and schistus combined; quartz; chalk (internally anidrite) with calcareous substances at times combined with dolomite; lastly calcareous chrystalline substance alternately with argillaceous schistus. The foreknowledge and foresight of the nature and the series of rocks which the workmen would have to encounter in making this Alpine tunnel, were such as to make these workmen remark "For philosophers the mountains are transparent."

The following table may serve to show the progress annually of the work and the proportions in which the mechanical excavations may have been accelerated until attaining an advancement of 1635 metres in the year 1870. On the 26th of December in that year this tunnel of the Alps, nearly eight English miles in length, and the work of Italian engineers alone, was complete.

Tables of the progression at the two entrances with the means ordinary and mechanical to the 26th of December 1870.

Specification of the work.	Bardonnecchia.			Modane.			Total for the two entrances.	
	Years.	Progress.	Total.	Years.	Progress.	Total.	Total work for each year.	Total general.
Progress by hand obtained in the years.		metres.	metres.		metres.	metres.	metres.	metres.
	1857	27,28		1857	10,80		38,08	
	1858	257,57		1858	201,95		459,52	
	1859	236,35		1859	132,75		369,10	
	1860	203,80	72500	1860	139,50	921,00	343,30	1646,00
	,,	,,	,,	1861	193,00		193,00	
	,,	,,	,,	1862	243,00		243,00	
Progress by mechanical means obtained in the years.	1861	170,00		,,	,,		170,00	
	1862	380,00		,,	,,		380,00	
	1863	426,00		1863	376,00		802,00	
	1864	621,20		1864	466,65		1087,85	
	1865	765,30		1865	458,40		1223,70	
	1866	812,70	635525	1866	212,29	4232,30	1024,99	10587,55
	1867	824,30		1867	687,81		1512,11	
	1868	638,60		1868	681,55		1320,15	
	1869	827,70		1869	603,75		1431,45	
	1870	889,45		1870	745,85		1635,30	
Total progress to the 26th December, 1870.		metres	708025		metres.	5153,30	metres.	12233,55

The effect of the bank of quartz which the labourers had to perforate on the Modane side in the year 1866 may be noticed in the above table.

Before taking leave of this part of the subject, it may perhaps be considered necessary to describe the dimensions of the tunnel. According to the project of execution, the tunnel should have been 12,220 metres long. The Southern entrance was fixed near Bardonecchia at the height of 1.335^{m},38, above the level of the sea. On departing from that point towards the middle, the tunnel ought to raise itself with an inclination or slope of 0^{m}50 per thousand. At the distance of 6110^{m}00 that is to say at the half of the subterranean way, there was presented a counter declivity towards Savoy of 22·20 per thousand. Consequently the height of the mouth of the tunnel at Fourneaux was found at

1202^{m}82 and the culminating point at 1338^{m}45 above the level of the sea. The greatest height of the stratum of mountain over the tunnel was calculated at 1,610 metres.

The actual measurements of the tunnel vary a little from the above. The positive length of the underground is 12,233^{m}55. The altitudes above the level of the sea, shown or indicated in the given plan, were found 43^{m}86 more than the reality, in such manner that the elevation of the Southern entrance is 1291^{m}52; that of the Northern entrance 1158^{m}96; that of the culminating point 1294^{m}59. The height of the stratum placed above the mountain remains the same as calculated.

In the working, the incline was also a little modified. On the side of Bardonecchia there is from the beginning an inclination of 0^{m},50^{p}0/00 per 800

metres. A slope of $1^{m},^{p}0/00$ per 2200 metres succeeds; from thence over again a declivity or slope of $0^{m},50^{p}0/00$ per 2600 metres, which being passed, a level tract occurs of $360^{m},50$. Beyond it there is a steady incline towards Fourneaux of $23^{m},^{p}0/00$ per 6273 metres.

The tunnel is broad enough for two double lines of rails. The perimetre of the transversal section is a curve of seven centres, which presents the greatest width of eight metres at the height of $1^{m},26$ above the rails and the breadth of $7^{m},87$ at the level of the rails, including two footways on the sides $0^{m},70$ width each. The height of the tunnel above the aforesaid flat corresponding to the keystone of the arch is six metres.

In order to excavate a subterranean place so gigantic, it was indispensable to open it by following a straight line from one side to the other of the mountain, as

well to provide for the need of ventilation as to be able to execute the necessary progress of the works. The railway, however, does not run in the straight line of the tunnel, but leaves aside the extremities, which remain open only for ventilation. The two tracts of the tunnel thus abandoned form in all 597^{m},40. Of this space 251^{m},30 are on the Southern side and 346^{m}10 on the Northern side. For the same were substituted two curved junction tunnels; one at the South of the length of 757^{m},07 with an inclination at the greatest of thirty per thousand; the other at the North of the length of 453^{m},70 with a declivity of twenty-three per thousand; in all 1210^{m},77 of junction tunnelling.

If one keeps account of such measure, and if to the same one adds the space in straight line not abandoned by the railway, which is 11.638^{m},15, one comes to

have a tunnel of the length of 12.848^{m},92, which is the true tunnel run through by the locomotive. If then to these figures are added also the 597^{m}40 of tunnel in a straight line left on one side, there will be 13.446^{m}32, which represents the total length of the subterranean place which they had to excavate.

CHAPTER III.

STRATA OF THE DISTRICT PIERCED BY THE TUNNEL.

BEFORE describing the means employed for excavating the Alpine tunnel (which will form the subject of a separate chapter) it may be well to say a few words about the strata of the district which was pierced by this tunnel. Under the direction of Professor Sismonda an exact register was kept of the rocks traversed and of all the mineralogical incidents, which register is too interesting to geologists not to be consulted elsewhere. It may be stated briefly here

that the bulk of the hill Fréjus, which the tunnel penetrates, is entirely formed of continuous beds or layers superimposed, relieved at the south-east by an angle of fifty degrees with the horizon. The perpendicular plan at these layers, which passes by their line of maximum inclination, makes an angle of forty-nine degrees with the general direction of the tunnel. One deduces therefrom that the real thickness of the beds traversed is about six-tenths of the length of the passage. The perforation recently accomplished is the equivalent of a vast hole by sounding line, which would have pierced the layers of the mountain to the extent of 7000 metres in a perpendicular line. One will comprehend the geological interest of this work, if one calls to mind that the deepest soundings executed in Europe with tools which bring to light specimens of the beds or layers reached, do not reach 1000 metres.

It is worthy of remark, that the results published down to the year 1871 have confirmed in all its principal details the theoretical section which Sismonda had traced for the Sardinian Government twenty-five years before.

There are not in the bulk traversed either plaitings or notable variations of inclination.

The upper layers are the first traversed at Modane.

The total thickness counted normally in the plans of the layers, and giving the amount of 7,000 metres, presents three successive principal zones of distinct nature.

1st. The upper anthraciferous soil.

2nd. The great calcareous and gypsous mass.

3rd. The lower schistus calcareous part.

The first zone is subdivided into

two: the anthraciferous soil properly so called (1,137 metres thick) and the quartz (220 metres thick).

The second zone, called calcareous and gypsous mass, is 500 metres in thickness. Its layers, bound to the quartz, show alternatives of calcareous crystallines, of anhydrites, and of talquous schistus mixed with quartz.

The third zone, the lowest and the thickest, contains calcareous schistus, little varied, comprising a very notable quantity of quartzous sand mixed, and in some sort combined with the calcareous part. One meets there frequently argillous schistus, grey and black, and talquous elements analogous to the silicate parts of magnesia. The total thickness of this third zone is 5,136 metres. It is worthy of remark that throughout the piercing of Mont Fréjus there was nowhere encountered mineral derangement nor even any true water spring.

CHAPTER IV.

MEANS EMPLOYED FOR EXCAVATING THE TUNNEL.

THE efforts of tunnelling, as already mentioned, were begun at the end of 1857 with the ordinary means. By this mode were excavated 725 metres of tunnel at Bardonecchia, from November, 1857, till the end of 1860, and 921 metres at Modane, from December, 1857, till the end of 1862. There remained to be excavated 10,587^{m},55, by the machines, of which machines a descriptive sketch will be given after a few words have been said about some subsidiary works.

The greater yard of Bardonecchia was

established at the east of the village of this name, near the stream of Rochmolles. There arose, as if by enchantment, in the midst of the rocks, the workshops for the repairs, the edifices of the compressors of air, the habitations for the workmen, and all the employed, &c. In order to put this yard in communication with the tunnel, were constructed 800 metres of roadway along the above-mentioned torrent, and near the mouth of the tunnel was raised a second yard for the operations more directly connected with the excavation of the subterranean place. The principal powder-magazine was placed near the stream Melezet, a little above its confluence with the Merdovine.

As already mentioned, the waters of the Alps were utilized or turned to account in the excavation of the tunnel. The torrent Melezet, near the small town or village of the Arnands, supplied the water

requisite for the yard of Bardonecchia. Thither it was conveyed by means of a channel in masonry of the medium width of $1^{m},20$ and of the capacity of a cubic metre, being more than 300 kilometres long, and covered throughout. This canal or channel, which was led along the sides of the mountains now more now less steep, passed under various little torrents, and finally it passed over the Merdovine by aid of a bridge-canal. To this water-course were appended several hydraulic buildings for the reception, discharge, and filtering of the waters.

The yard on the Northern side was placed on the flank of the village of Fourneaux, near the confluence of the rivulet Charmaix, at about 2,500 metres from Modane. It was divisible into two parts, one of them below on the bank of the Arc, along the road of Moncenis, the other on the declivity of the mountain,

near the entrance of the tunnel, at about 106 metres from the bottom of the valley. Here were reproduced the same works as those erected on the side of Bardonecchia, with those variations only which were required by the different conditions of the places. The channel destined to provide water for the compressors was derived from the Arc, near the mouth of the Charmaix. It flowed parallel to the river from which it derived itself, as far as the water-wheel building for a length of 640^{m}, elevating itself always above the waters of the Arc, until it attained the total height of six metres. After the leap it entered into a canal of discharge, of the depth of rather more than six metres under the natural soil, and with a breadth of beyond twenty metres between side and side. The minimum capacity of the canal was of six cubit metres.

Another derivation was made at Four-

neaux, from the river Charmaix, in order to move the machines intended for ventilation, because it is to be noted that on that side, the inclination of the tunnel being greater, more powerful means were required than on the side of Bardonecchia, where from the beginning, an ordinary ventilator and afterwards a ventilator with centrifugal force was employed. At Fourneaux, instead, were substituted machines bell-shaped, called aspirators, moved by machines of columns of water; but for the forced conduct was necessary a fall of seventy metres of height. For this they provided by means of the canal of derivation, which carried the waters of the Charmaix to the regulator edifice, from which departed the forced conductor intended for the machines of columns of water. However, the whole power was not employed in

these machines; a part supplied the moving force in the workshops.

On the side of Fourneaux deserves to be mentioned the self-moving plane, which united the yard of the repairing workshops, placed at the bottom of the valley, with the lesser yard open on the flank of the mountain, near the orifice of the tunnel, and at about 106 metres above the plane. Along the inclined plane run or slide two tender cars, joined by means of a metallic cord which is mounted on a pulley. Filling itself with water, that which is at the summit descends, aiding with its own weight the ascent of the other, on which are placed the materials to be raised. A powerful curb applied to the great pulley serves to regulate its speed.

The Water-column compressor.—It is most simple, and it results essentially from a siphon inverted, which on one side

communicates with a water-reservoir, and on the other side with a reservoir of air. The water descends into the first branch of the siphon making its way through a supply valve, and mounts again into the second, compressing there that air which it finds there, which, arrived at a sufficient degree of elastic force, opens a valve which lets it into the air reservoir. Then a valve of discharge opens itself, and when all the water is gone out from the second branch of the siphon the operation recommences. As for the movement of the valves of supply and of discharge, it is regulated by means of a little machine of columns of water, and the air in the reservoir is maintained at constant pressure by means of a column of water which communicates with a basin placed at a certain height.

In the works of Bardonecchia were ten compressors by column of water, divided

into two groups, which could be worked singly or two at a time. Moreover, each compressor could be started, or set at rest at pleasure, without interrupting the action of the others. At twenty-six metres above the regulator plane, or plane of discharge, was the reservoir of compression, into which communicated all the columns of the compressors. The waters at the reservoir of compression were brought by means of big tubes of iron, which received them from the canal of derivation placed at twenty metres higher. On the hill-side above, and at fifty metres over the level of discharge above mentioned, was the regular reservoir, of a capacity of 400 cubic metres. All the system received its complement from the great conduct of air, which, detaching itself from the recipient, ran along the temporary road, following the various inflexions or bendings of it, being supported

on brick-work pillars, and went to carry the compressed air into the tunnel as far as the extreme limit of the advancement of the works.

Pump-Compressors.— The compressors by column were employed in the early days of the work with advantage on the side of Bardonecchia; it was otherwise at Fourneaux, because that, these requiring a very strong push of water, the rivulet Charmaix, the only one capable of furnishing it on that side, in some months of the year has not a sufficient supply. The Arc, which glides at the foot of the mountain within which was excavated the tunnel, transports all the year a quantity of water much superior to the requirement, but it was only possible to get at most a fall of six metres, by digging a channel parallel to the course of the torrent.

These circumstances and the distrust

for any other system of compression induced the engineers at first to raise the water by means of pumps into a suspended reservoir at a height above of twenty-six metres, from which the water fell back into the compressors to be then again raised and to secure thus the continnal production of compressed air. But Sommeiller first among all understood that in the artificial elevation of the water there was a great loss of force and of money, and this new mechanism was no sooner installed than his fertile spirit had already found the other system of compression, which acts without the fall of twenty-six metres, and which with a third less of expense gives the quantity of air triple of that supplied by the compressors by column.

Such an arrangement is the hydropneumatic compressor by pump. It is formed essentially by a horizontal pump tube, in which works a piston by hydraulic wheels.

At the heads of the body of pump are elevated two vertical cylinders in part only full of water, and in which the two liquid columns are divided by the piston interposed. This piston then, endowed with alternate rectilinear motion, alternately raises and lowers the two columns in the respective cylinders, effecting the aspiration and the compression of the air.

The new machines were purposely constructed for the yard of Modane, and and when it became necessary to increase the number of compressors by column of water for Bardonecchia, because of the greater quantity of air which was required for the works of that yard, it was thought that these might be substituted at the Southern entrance as far more simple, besides working without jerks and with any fall of water.

Perforating Machine.—An entire description of this complicated machine would

far exceed the limits of this little work. It will not, therefore, aim at giving more than a few general indications. Let one imagine to one's self a frame of iron composed of two long and very solid bars disposed in parallel lines. In the interior of the bar is placed the mechanism of progression, the cylinder-striker with the chisel-holder and the extremity of the tube-conductor of the air compressed. Such instruments are constructed in a manner to produce the following results: automatic movement of percussion and of rotation of the chisel, and also of pushing forward the same into the deepest practicable mining holes. This last movement is not constant, but subordinate to the greater or lesser hardness of the rock. The stroke is given by a piston which carries the perforator iron and oscillates freely in a pump tube. In the oscillating it alternately opens and shuts some valves

which let in and set free the compressed air. The lower end of the piston is larger or broader than the upper, and the pressure of air is found to be in direct ratio to the surface on which it acts. From this combination it arises that in its forward movement the stroke of the perforating tool is more powerful than in the return movement. In order to prevent the violent strokes of the piston against the sides of its cylindrical prison, the inventor had the idea to make it dash, as much anteriorly as posteriorly, against a volume of air, reinforced for greater security by a cushion of caoutchouc. In its chamber, well quilted, the piston has a free movement and is able to fulfil its violent action without shaking its pump tube.

Besides the rectilinear movement of go and come, the piston has to revolve at every stroke in order to imitate the work

of the miner. That movement, most difficult to be executed automatically, is impressed by a square rod which enters air tight into the body of the piston, escaping when it proceeds in front and re-entering into the case or sheath when it returns back, in the same manner as of a sword half out of its scabbard. The rod, or we will say the sword, in order not to abandon the comparison, is surmounted by a solid wheel which forms the guard of it. The wheel is furnished in its circumference with sixteen teeth and an iron catch which obeys the movement of another rod, catching itself at each blow in a tooth, and making consequently the perforator piston turn the sixteenth of a circle at each blow. This second rod receives the impulse by means of a special and surprising mechanism, that is to say by a second machine of compressed air, machine in miniature which

could be held in hand, and which reproduces exactly, in a scale infinitely small, the working of a steam-engine. The top of the rod, plunging itself into this slender apparatus and expanding itself after the fashion of a piston, there receives from the compressed air a rectilinear movement easily transformed into a circular movement by means of an eccentric or small tooth-wheel, and that iron catch or finger. At last the perforating apparatus carries itself forward by itself pushed by a spring placed behind the body of the pump. Then when the hole of the mine is deepened twenty centimetres, the handle of the foil, furnished with a hammer, strikes on a button, raising a catch or claw which suspends the play of the spring, and this, disengaged, or set free, extends itself and pushes forward the apparatus until the claw meets a new tooth.

A constant watering being considered

indispensable, there is attached to every perforator a long and thin metallic tube destined to carry a stream of water into the site where the chisel works. The whole machine occupies the very limited space of $2^m,10$ of length, of $0^m,23$ of breadth and of $0^m,40$ of height, and it can be easily transported by two workmen.

Process of the mechanical perforation.— It may be well now to allude to the manner in which the mechanical perforation proceeded in the interior of the tunnel. To him who enters it, and pursues his way through the length of it to the part where the perforators work, it appears in quite three distinct portions. The first is the part already faced. The second space follows in which the works of scaffolding and enlargement have place. In this tract, in the midst of a forest of timber forming the centres for the facing

work, the props or supports to the rock and the temporary bridges, the miners work at the enlargement of the section, the masons at the raising of the pier-droits, the carpenters at the erection of the centres for the arches, and gangs of other workmen either at sheathing the vault with planks, or in a variety of ways besides, and yet all these different artisans advance almost always in the same order by measure of the total advancement of the work. Having passed beyond this space, which is maintained the shortest possible, one enters into the preparatory gallery, excavated with the compressed air and with the perforators. This part of the tunnel is as an open breach in the rock in order to render more easy the excavation in great section; and it is on the advancement obtained in it that depends the celerity obtainable in all the works which follow.

Into the tunnel of advancement penetrates and prolongs itself the two-fold railway, which traverses the two first spaces of tunnel and finishes only at a short distance from the front of attack. There the railway is further extended, when requisite, by the addition of two metre rails, *i.e.*, rails two metres long. The double rail has the customary breadth of the ordinary double rails, and thus it is only a branch of network of temporary roads. The frame of the perforators is moved on this double rail, and is able, in case of need, to be drawn out of the tunnel and led on the external yards like the service-vans. Other double rails of less amplitude or size, are disposed parallel to the principal, and serve for the circulation of the little carts or little waggons on which are exported the heaps of the fragments of rock produced by the explosion of the mines of advancement.

Under the principal double rail is excavated a large furrow or continuous trench, which is prolonged with the progressing of the advancement, and in this trench are placed the tubes which carry to the attack the compressed air, the water, and the gas. The trench is, however, so covered over, that the tubes enclosed may not have to suffer from the remains or detritus of rock hurled by the mining.

In the preparatory gallery are established two doors of safety, constructed with beams and large planks and which are turned on two hinges. They, when they are closed, constitute an efficacious rampart against the stones hurled by the explosion of the mines of advancement; and, when open, they leave free to all the movements the entire section of the tunnel.

These doors can be brought forward

when needed, that is to say as often as their distance from the front of attack is made excessive, or in other words, when the work has progressed from sixty to eighty metres.

The section of the preparatory gallery has a breadth of about m3·40, and a height of about m2·40, and is maintained as long as may suffice to leave free space for all the operations of progression, which ought to be accomplished without being impeded by the work of enlargement, or causing obstruction to the latter.

The machine presents itself to the front of advancement armed by nine or ten perforators, some laid parallel to the axis and against the middle, others on the perimetre and in direction diverging from the axis at right and left, high and low. To every perforator are annexed two flexible tubes, the one for the com-

pressed air, the other for the water, which is projected into the holes. Around the machine are placed: 1st. foreman; 2nd. four engineers; 3rd. two stonecutter miners; 4th. eight labourers to work the chisels; 5th. nine workmen to tend the machines, the compressed air and the water; 6th. five boys specially appointed to the working of certain parts of the perforators and to the oiling or greasing of the machinery; 7th. eight labourers assigned to the service of the perforators: total thirty-seven persons, besides a few others whose business it is to communicate with divers depôts and with external yards.

The works are lighted with gas carried along the bottom of the tunnel, like the compressed air, in tubes of iron from the gasometer established outside near the workshops of repair.

For every attack are bored on the average eighty holes of the depth of from

seventy-five to eighty centimetres; the greater number of these holes are bored towards the central part of the front of attack, where they have to open the breach, which is blasted before firing those of the perimetre.

The boring of the eighty holes being completed the second period of the operation commences.

The connection between the compressed air and the machine being stopped, this last is withdrawn to a distance sufficient to place it in safety behind the safety doors or guards; and the firemen with their tools and with the powder and the train, succeed immediately the perforators for proceeding to the charge of the mines; that done, at the first discharge they make the mines of the breach blow up, and do not apply the fire to the others if the breach is not first open; and often they are compelled to blast again the

mines which in the explosion have not produced the desired effect.

The work of the firemen is greatly facilitated by a strong rush of compressed air which is drawn to the bottom of the tunnel, and which carries off the dense smoke produced by the combustion of the powder.

The blasting being done with, the firemen abandon the ground to the clearers away. These come next pushing forward and quickly small trollies, and while the compressed air continues to issue from the conduits, in order to purge and refresh the atmosphere, by some these trollies are loaded with the heaps of fragments of rock, whilst by others the little waggons thus loaded are pushed from the forward works beyond the gates of security, where they are left to those labourers charged to make go out of the tunnel the remains or detritus, and thus

they persevere until all the quantity of stones produced by the explosion of the mines has been got away; and with this removal finishes the third and last period of attack. Then is prolonged immediately the main rail of one line of rails if convenient, and the body of the machine is again brought forward against the rock, to commence another attack; but for this a fresh set of men are employed, whilst the first workmen, once they have got the body of the machine behind the doors of safety and cleaned the perforators, having changed some of the perforators and repaired others and put in good order the accessories, have finished their assigned work, and go out of the tunnel.

CHAPTER V.

COST OF THE TUNNEL.

THE law of the 15th of August, 1857, which authorizes the government of the King of Sardinia to undertake the works of the piercing of the Alps between Bardonecchia and Modane, calculates provisionally the expense at 41,400,000 lire, or a little more than £1,600,000 of English money. In the same the company of the railway Victor Emanuel, was to contribute for the sum of 20,000,000 lire.

After the cession of Nice and Savoy, an international convention was entered into with the French Government, ap-

proved with the Royal decree of 18th June, 1862, in which France assumes the charge of 19,000,000, but payable only on condition that the works were terminated within twenty-five years. A premium of 500,000 lire was promised for every entire year gained on those twenty-five years; but in case the works should last less than fifteen years, the premium was to be 600,000 lire for each entire year spared or saved on the fifteen years.

The Italian Government, in order better to secure the completion of the work before 1871, which would procure to the country great advantages, and bring to the finances a considerable benefit through the large sum which France would have to pay by title of premium, considered it convenient to conclude in date of the 31st of December, 1867, a treaty of concession with the engineers Grattoni and Sommeiller, in force of which they bound

themselves by agreement to give the work completed before the expiration of the year 1871 for the price of 4,617 lire the lineal metre.

Taking into account the expense defrayed by the new concession, without alluding to the sums paid by the Government for the construction of the works already completed, one arrives at a result little short of seventy-five millions of lire for the total expense of the work of the piercing of the Alps.

The number of officers and others assigned to the undertaking consisted: 1st, in the scientific direction constituted by the engineers Grandis, Grattoni and Sommeiller, represented on the place by an engineer of section at each of the two entrances, on whom depended a sub-engineer, a head machinist and a competent number of foremen at the service of the compressors, of the workshops and of the

external works, a chief of the yard at the tunnel with three changes of assistants, foremen and principal men in the gangs of labourers; 2nd, in the economical survey for the administrative acts, which in the last three years was transformed into technical inspection, to which was appointed the Commander Valvassori for the purpose of watching that the agreement between the Government and the technical direction should be duly carried out.

The number of the workmen employed at the excavation of the tunnel, for each of the entrances, was 1500 in the winter and 2000 in the summer, besides many others employed by the sub-contractors for various materials. Including the families which many of these workmen brought with them, the engineer Grattoni calculates on the average at more than three thousand the persons who owing to the works, established themselves at

Bardonecchia, where the population, which consisted of one thousand, was in a few years quadrupled. An influx of workmen, if not equal, certainly little inferior, must have taken place also on the side of Modane.

It would be very desirable to give an account here of the material of each yard. It would however be difficult to give such an account with accuracy because the novelty of the undertaking, the inexperience of the personal, the application of new methods and a hundred other difficulties have given origin to a great number of alterations and improvements, which increased considerably the expense of the material and the material itself. Wishing nevertheless that the reader may be able to form to himself an adequate conception of the importance of such works and of their many needful requirements, I will transcribe in this place

a model of a normal yard, based on the experience acquired in the excavation of the tunnel of the hill of Fréjus, and published by Grattoni in his report of 1865 on the application to the tunnels of the Central Alps of the mechanical means employed at the piercing of the Alps between Bardonecchia and Modane.

NORMAL YARD WITH THE VALUING OF THE OBJECTS ONE BY ONE WHICH COMPOSE IT.

	Lire.
1. Purchase of land, say	100,000
2. Conducts of waters by means of tubes or culverts, canals of discharge, cataracts, filtering basins, &c., ...	250,000
3. Edifice for the compressors, localities for No. 8 compressors	240,000
4. Sheds for the reservoirs	25,000
5. Workshops of repair	100,000
6. Central magazine	30,000
7. Succursal magazine	24,000
8. Lime stores	12,000
9. Magazines for the timber, coal, argillaceous, earth, &c.	18,000
10. Powder magazine	10,000
Carried forward	809,000

	Brought forward	809,000
11.	Dwelling houses for the officers and artificers	150,000
12.	Habitations for a thousand workmen .	300,000
13.	Very large waiting room at the entrance of the tunnel	8,000
14.	Infirmaries	8,000
15.	Magazine for the subsistence . .	40,000
16.	Stable for fifty horses	10,000
17.	Movement of materials for the formation and arrangement and levelling of sites, excavations of rocks, walls of support, &c., &c.	100,000
18.	Roads of service	45,000
19.	Palisade of enclosure of the yards . .	10,000
20.	Gas works	25,000
	Carried forward	1,505,000

MECHANISMS.

21.	Compressors and hydraulic movers 8 in number .	£480,000	
22.	Conservators five in number	160,000	
23.	Conduct of external air .	60,000	
24.	Divers implements or tools, plugs, indicators, paddle-doors, slide valves, &c., &c.,	40,000	
25.	Furniture of the workshops, hydraulic mover, transmissions, driving bands, &c., &c.	140,000	

	Brought forward		1,505,000
26.	Expenses for provisions of every kind.—Machine carriages, perforators, tubes of iron and cast iron, cloth, caoutchouc, &c., &c., rails, platforms, waggons, magazines refurnished, iron, steel, &c., &c., from whence to be in a state to commence the works	600,000	
	For completion . . .	15,000	
	Total of Mechanisms		1,495,000
	Total		3,000,000

According to the statement above, the expense for each of the two yards of Bardonecchia and of Modane, has not been certainly inferior to three millions, without keeping account of the greater expenses due in the beginning to the want of experience in the workmen and to the imperfection of the instruments which it was intended to apply for the first time, and which naturally have been obliged to be modified and sometimes even entirely reconstructed.

CHAPTER VI.

BRANCH-LINES.

It is proposed in this chapter to give a brief narrative of the railways of approach to the tunnel through Mont Fréjus commonly called the Mont Cenis tunnel. The railway intended to form a junction with the line leading from Turin to Susa and the Southern entrance of the tunnel is detached at 800 metres west of the new station of Bussoleno, or in other words at the distance of about forty-seven kilometres and a half from the station of Turin and at the height of 440 metres above the level of the sea; it

crosses the Dora upon a bridge of three arches, and, running by the skirts or slopes of the mountains situated at south-east of Bussoleno, arrives at the tunnel of Meana, one of the works most difficult and most important of this line, excavated for the length of 1100 metres on a rise at the foot of the counterfort Sestrières. On coming out of this tunnel is met the station of Meana which is distant from that of Turin about fifty-four kilometres, and which is placed at the height of 594 metres above the level of the sea, and of ninety-nine above that of the station of Susa.

Leaving the city of Susa to the north, at the distance of 1800 metres, the new railway traverses an Alpine region, broken by frequent backs of mountains and by deep ravines, which had to be overcome by means of a series of tunnels and of viaducts. Having passed beyond the tunnel of Balme, 539^{m} long, it enters into a fer-

tile soil, covered by fruit-bearing trees, and arrives at the station of Chaumont, placed at 770 metres of height above the level of the sea and distant sixty kilometres and a-half from Turin.

The railway continues to run along the slopes of the mountains which enclose on the south the Dora, and traverses still several tunnels, among which are remarkable those of Exilles, of 1767^{m}, and of Serre-la-Voute of 1094^{m} in length. On leaving this last underground, it crosses a second time the Dora, and from there as far as Bardonecchia leaves almost entirely the mountain side to follow the course of the river; it arrives at the station of Salbertrand, at seventy kilometres from Turin and at 1007^{m} above the level of the sea; it traverses a third time the Dora at Pont-Ventoux; it traverses it a fourth time a little before arriving at the station of Oulx, placed at seventy-six

kilometres from Turin and at 1066^{m} of elevation above the level of the sea; it ascends again the torrent of Bardonecchia along the right bank; it passes over on the left near Savoulx; it repasses on the right near to Planches; at last it traverses the rivulet Melezet and reaches the station of Bardonecchia, situated at 1258 metres above the level of the sea, and distant eighty-seven kilometres from Turin, and 1000^{m} from the village from which it takes its name. Afterwards, about half a kilometre from the station of Bardonecchia is found the definitive entrance of the great tunnel, at the height of 1269^{m} above the level of the sea.

In a word, from its junction point up to Bardonecchia the railway is concealed in twenty-six tunnels of a length comprehensive in round numbers of eight kilometres upon a total extent of forty kilometres; it passes over fifteen great

viaducts; it goes through five stations (Meana, Chaumont, Salbertrand, Oulx, Bardonecchia) and makes a stop at Beaulard. The difference of level between the starting point of the new line and the entrance of the great tunnel is 829 metres; the medium declivity is $20^{m}50$ per thousand; the greatest is thirty per thousand.

The branch line, very lately constructed on the side of Savoy, has the length of twenty-one kilometres, between Saint Michel and the Northern entrance of the great tunnel. It is notable for the engineering skill with which are overcome the obstacles arising from the Alpine and wild or savage nature of the places; there are met eleven tunnels of the comprehensive length of 3,186 metres. The elevation above the level of the sea at Saint Michel is 710 metres; at the entrance of the tunnel it is 1,156 metres; thus the

difference of level between the two extremities is 446 metres; the medium declivity or slope is 21 per 0/00; the greatest declivity or slope is 30 per 0/00.

At the distance of a kilometre and a half from Saint Michel, the railway on the right bank of the Arc passes on to its left bank, which it does not again leave. At ten kilometres it reaches the station of La-Praz, and at fifteen and a half that of Modane. Somewhat before arriving at this last, it passes through the village of Fourneaux, where are seen the vast edifices constructed for the excavation of the tunnel of Mont Fréjus.

Beyond the Modane station, the railway runs up the side of the Arc for about two kilometres; from thence it curves round the village of Modane, and raising itself by degrees along the side of the overhanging mountain, returns towards Fourneaux, but at a height of 100

metres above the bottom of the valley; there it hides itself in the great subterranean place, after having run through little more than twenty-one kilometres departing from Saint Michel.

CHAPTER VII.

CONSEQUENCES OF THE PERFORATION OF THE ALPS.

THE Alps, which on the north gird Italy, and separate it on the one side from the French nation, and on the other from the German and Illyrian nations, have been a grave obstacle to a rapid development of Italian commerce and industry. Whilst the ports of Marseilles, of Havre, of Amsterdam, of Hamburg, and all the most flourishing cities of the European continent were closely joined by a wonderful net of railroads, the Italian cities saw themselves condemned to isolation because

of that gigantic chain, long believed inaccessible to steam. It was a work, therefore, of vast utility and advantage to break through a barrier so damaging to the commercial relations of Italy, without its ever having proved efficient in shutting it out from foreign invasions.

It is a fine boast of our age that of having initiated and completed the greatest works which can honour the genius of man, such as are the junction of two continents by means of the trans-atlantic cable, the canal of Suez, the railway of the Pacific, the piercing of the Cozian Alps. In vain should we seek a parallel in ancient works, which commonly aimed only at gratifying the ambition of some potentate, or if they aimed at general utility, statecraft, egotism and distrust held them fettered in limits too small and narrow of the nation which had raised them. On the contrary, the genius of our

times exercises itself in a more vast field and aims at binding in brotherly union all the people of the earth, and its works are so much the more praised and blessed as more numerous are the nations on which they shed their beneficent effects.

The importance of the perforation of the Alps must appear manifest, whether it be regarded in its scientific aspect or be considered with a view to its economical, moral and commercial advantages.

The result obtained has been a true triumph of science, which will have the most useful consequences. The objections which were raised by the opposers of that undertaking are well known; some feared that rocks would be met with of a nature so hard as to make the effort to break through them useless; others were afraid of powerful springs of water which would have submerged the excavated subterranean place and rendered

impossible the prosecution of the works; some pretended insupportable the heat which would be encountered in the deeper bowels of the mountain; others finally were apprehensive about the want of air for respiration by working the tunnel without shafts. To tell the truth, this last difficulty was the most grave; men eminent for genius and for learning, among whom was Humboldt himself, believed in it. But all the obstacles enumerated, in proportion as the work progressed, fell the one after the other, thanks to the new and wise application of the scientific principles; and this noble victory, won by the human mind over error and over prejudices, will mark a memorable epoch in the history of inventions and discoveries, and will be fruitful in future of other useful results.

Faith in the efficacy of the instruments employed to pierce the entrails of the hill

of Fréjus, is such, henceforward, that doubt is not felt as to their applicability to other places of the Alps not less difficult. The piercing of the Saint Gothard, which a few years ago was held by many an utopia, at the present time does not encounter any opposition with regard to its execution, which may, sooner or later, be undertaken. Thus among the consequences of the perforation of the Cozian Alps, not the least important may be that of contributing directly to the success of like undertakings in other parts of the Alps, because the experience acquired in the excavation of the tunnel of the hill of Fréjus, the bringing to perfection of the systems, the improvements in the machinery, and the opportunity to find workmen well up to their work, will all concur to facilitate similar works, at once lessening their cost and shortening their duration.

The commercial advantages will be great, although possibly they may have been overrated. It is certain that through the Mont Cenis tunnel, as it is called, will be made the traffic of Upper Piedmont with France, with Spain, with Western Switzerland, with Belgium, with Holland, with England; through that way also Lombardy, Venice, Modena, Bologna and Ferrara, will effectuate their traffic with the Central and Southern Departments of France, and with Spain; but not that with the Northern Departments of France, with Switzerland, with Belgium, with Holland, with England, which more directly and more rapidly they will make by the Simplon or by the Saint Gothard, as soon as they may be traversed by a railroad. As for the commerce of Italy with the German, Hungarian, and Slave countries, they will be effectuated by the ways of the Saint Gothard, of the Brenner, of Tarvis, of Adelsberg.

Many affirm, but it would seem erroneously, that the transit trade of the Indies through the Canal of Suez must take the way of the Cozian Alps. The mercantile goods coming from the seas of the Levant, except those of great value, will probably be sent by the sea-way as far as the ports of Trieste, of Venice, of Genoa, of Marseilles: of these four ports the only one which can profit by the new line is that of Genoa, for the mercantile goods directed to Central and Northern France, to Western Switzerland, to Belgium, to Holland, to England; but who does not see that Genoa will never be in a state to withstand the competition of Marseilles, which, being placed at the mouth of the valley of the Rhone, communicates directly with those countries by means of lines of railroads of less expensive working than are those by which the Genoa and Cozian Alps line would carry on their

trade? To Genoa will be reserved a great opening; when by means of the railroad of the Saint Gothard it will be joined with the countries of Central Europe.

The passengers coming from the East, to avoid the weariness of the sea-passage, will prefer in many cases to land at the port of Brindisi, where they will profit by the railroad which traverses the Italian Peninsula. Of these, only a part will choose the way of the Cozian Alps, and principally such as intend going to the central cities of France. Many will take other roads; if they are going to the Southern cities of France or to Spain they will choose the Ligurian railway, which may now be said to be completed; if instead they are bound for the Northern cities of France, for Switzerland, for Belgium, for Holland, for England, they will prefer the way of the Simplon or that of the Saint Gothard; if they are on the

way to Germany or the Countries of the Austro-Hungarian Monarchy, they will choose the route of the Saint Gothard or the Brenner, or the other more Eastern passes of the Alps.

Therefore by the hill of Fréjus will pass only a portion of the merchandise and of the passengers landed at Brindisi; nevertheless, if to this part shall be added the transit of the merchandise directed from the Austro-Hungarian provinces to Southern France and to Spain, which will be carried on by the new line, one will be obliged to admit that even when restricted to the limits just mentioned, the transit-trade of the Cozian Alps railway will not fail to be of importance.

The advantages which this railroad will bring to industry will be readily observed, if notice is taken of the great facility which it offers for utilizing the numerous currents of water which are encountered in the

vallies of the Dora and of the Arc. With little expense and in a short time would be able to be got the primary materials, and to be exported the products of the manufactures which could be established on those copious and perennial water-courses. In order to form to one's self an idea of the importance of this motive force, it may be sufficient to note that from Chambéry to Modane and from Bardonecchia to Susa one would be able to obtain the work of beyond 70,000 horse-power, whilst all the steam-engines together of Belgium, which is one of the most industrious countries of Europe, do not represent but 25,300 horse-power, of which 15,600 horse-power is employed to excavate coal which is to feed the remaining engines. Let it be added that the vallies hinted at abound in minerals, in timber, in herds of cattle, and that the valley of Maurienne especially possesses much metallic

riches, which till now, through defect of communications, have remained in great part abandoned, and that henceforth they will acquire great value through the convenience which the new railway offers to be able to transport them. Therefore, if the people do not fall short of their task, we may reasonably hope that within a brief period those countries will change their squalid aspect and take their place among the busiest and richest centres of European Industry.

THE END.